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Development of a deep-penetrating, compact geothermal heat flow system for robotic lunar geophysical missions

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Geothermal heat flow measurements are a high priority for the future lunar geophysical network missions recommended by the latest Decadal Survey of the National Academy. Geothermal heat flow is obtained as a product of two separate measurements of geothermal gradient and thermal conductivity of the regolith/soil interval penetrated by the instrument. The Apollo 15 and 17 astronauts deployed their heat flow probes down to 1.4-m and 2.3-m depths, respectively, using a rotary-percussive drill. However, recent studies show that the heat flow instrument for a lunar mission should be capable of excavating a ~3-m deep hole to avoid the effect of potential long-term changes of the surface thermal environment. For a future robotic geophysical mission, a system that utilizes a rotary/percussive drill would far exceed the limited payload and power capacities of the lander/rover. Therefore, we are currently developing a more compact heat flow system that is capable of 3-m penetration.

Because the grains of lunar regolith are cohesive and densely packed, the previously proposed light-weight, internal hammering systems (the so-called 'moles') are not likely to achieve the desired deep penetration. The excavation system for our new heat flow instrumentation utilizes a stem which winds out of a pneumatically driven reel and pushes its conical tip into the regolith. Simultaneously, gas jets, emitted from the cone tip, loosen and blow away the soil. Lab tests have demonstrated that this 'proboscis' system has much greater excavation capability than a mole-based heat flow system, while it weighs about the same.

Thermal sensors are attached along the stem and at the tip of the penetrating cone. Thermal conductivity is measured at the cone tip with a short (1- to 1.5-cm long) needle sensor containing a resistance temperature detector (RTD) and a heater wire. When it is inserted into the soil, the heater is activated. Thermal conductivity of the soil is obtained from the rate of temperature increase during the heating. By stopping during the excavation, it is possible to measure thermal conductivities at different depths. The gas jets are turned off when the penetrating cone reaches the target depth. Then, the stem pushes the needle sensor into the undisturbed soil at the bottom of the hole and carries out a thermal conductivity

measurement. When the measurement is complete, the system resumes excavation.

RTDs, placed along the stem at short (~30 cm) intervals, will monitor long-term temperature stability of the subsurface. Temperature in the shallow subsurface would fluctuate with the diurnal, annual, and precession cycles of the Moon. These thermal waves penetrate to different depths into the regolith. Long-term monitoring of the subsurface temperature would allow us to accurately delineate these cyclic signals and separate them from the signal associated with the outward flow of the Moon's endogenic heat. Further, temperature toward bottom of the 3-m hole should be fairly stable after the heat generated during the excavation dissipates into the surrounding soil. The geothermal gradient may be determined reliably from temperature measurements at the RTDs near the bottom. In order to minimize the heat conduction along the stem from affecting the geothermal gradient measurements, we plan to use low-conductive materials for the stem and develop a mechanism to achieve close coupling between the RTDs and the wall of the excavated hole.

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